SPS Crab Cavity Test Day II
MD Planning Overview

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8 May 2018 - CERN

Outline

- **Overview**
- **Current Status**
- **MD program phases**
  - RF-beam commissioning
  - Transparency
  - Performance
  - High Intensity
- **MD Preparation**
- **Summary**

Overview

- **Scope of the program:**
  - Determine the operational feasibility, transparency, short & long term effects of crab cavities with protons.

- Dedicated MDs (8am-6pm) were negotiated in the SPS on Wednesdays.
- The current minimum estimate is ~**10 MD slots** to fulfil the main goals

- For more details, **please refer to the accompanying MD plan**.
- Main goal is to get feedback from this meeting
  - **Please do not hesitate** to express any concerns, doubts, thoughts about the plan.

- **First MD** is tentatively planned for **23/05/18** .

Overview

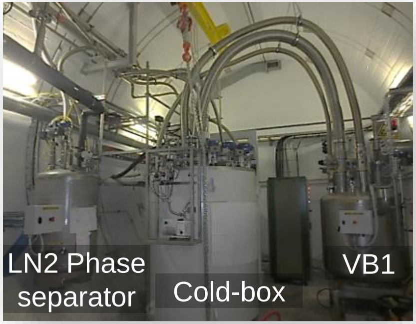
- The MDs were split into 4 main categories (for 2018):
  - RF-beam commissioning (2x10h)
  - Transparency (1-2x10h)
  - Performance (1-2x10h)
  - High intensity (2x10h)

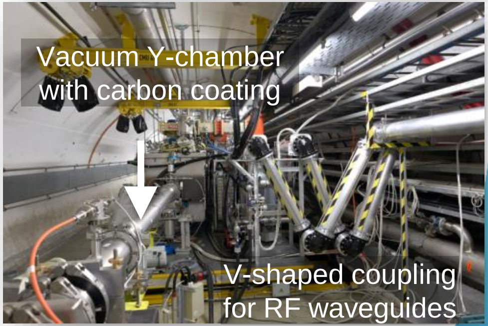
- Before going to high intensities, a **special MPP** will be held to **assess the cavity performance** concerning protection issues.

- Will perform **failure studies in parallel** during the MDs, as the beam parameters vary.

Current Status – Installation Overview

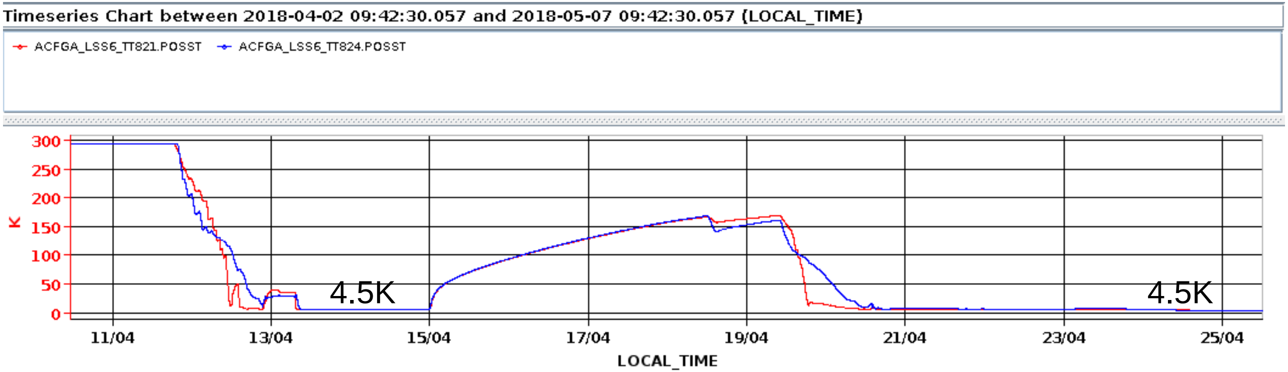
- SPS-BA6 Installation (YETS 2017-18)





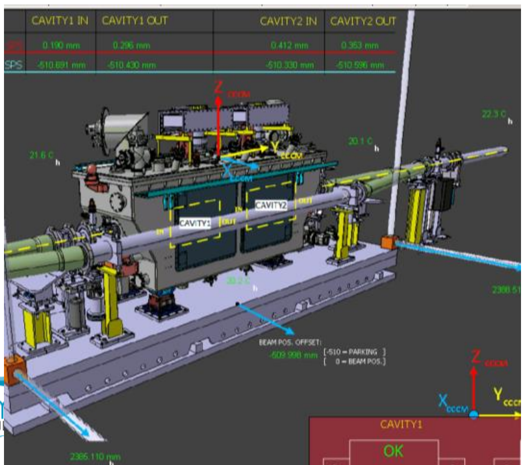
Current Status – Cool-down and Conditioning

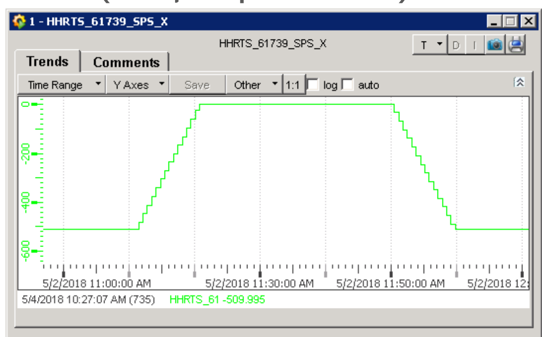
- First frequency measurements (in-situ)
  - **@295 K**: Cav1: 399.959 MHz, Cav2: 399.992 MHz
  - **@4.5 K**: Cav1: 400.638 MHz, Cav2: 400.689 MHz
- Cool-down start (see the talk by K. Brodzinski)
- RF conditioning, cavity 1
  - 100 μs - 15 ms pulses up to 10 kW



Current Status: Equipment Check

- First MD on 02/05/18.
- Cavities moved at 4.5 K with 60% Helium level
- Test of interlocks: vacuum valves, access, liquid level
- Safe position table for beam confirmed by position switches (Parking, experiment)
- Absolute positions measured on line by EN Survey with FSI system, well within requirements
- Lateral position adjusted from BA6 (2.5 μm precision)





Beam Parameters for Crab Tests

	Units	Value
Energy (Cycling)	GeV	26, 270
Coast Energy	GeV	270
Intensity	p/bunch	2e10-1.2e11
RF Voltage	MV	3.0
4^{th} Harmonic Voltage	MV	0.0**
Bunch Length	ns	1.0-2.0
Longitudinal Emittance	eVs	0.1-0.35
Betatron Tunes		26.13, 26.18
$\beta_{x,y}$ (CC location)	m	30, 77
D_x (CC location)	m	-0.5

- Information on bunch parameters for each specific measurement can be found here.
- A table of optics parameters at the key elements can be found in the backup.
- **If there are DA issues, 4th harmonic may need to be introduced to stabilise a shorter bunch.

MD 1 & 2: RF-beam commissioning

- **Aims**
  - To synchronise the main rf to the crab cavities.
  - To setup and calibrate the crab cavities at 26 GeV.
  - To verify their behaviour and validate the LLRF control systems (at 4.5K).

- **Steps:**
  - Beam synchronisation at 26 GeV with low CC voltage (300 kV)
    - Close feedback loops, injection transients. Find minimum voltage where we see a crabbing signal (BPMs/HT/WS)
  - Beam centering with medium CC voltage (750kV - 1MV)
    - Vertical orbit scan to see output from IOT.
    - Horizontal scan to check field asymmetry.

MD 1 & 2: RF-beam commissioning

- **Steps (cont):**
  - Check aperture around the CCs
    - CCs on low voltage. Not aggressive. Less aperture in V compared to H.
  - Calibrate CC phases and increase voltage to ~3.3 MV
    - Refer to the document for specific procedures on how this is done.
  - Ramp to coast energies
    - Cavities in transparent mode, with cavity frequency set for synchronisation at 270 GeV.
    - At the end of an MD(1 & 2), inject and try a ramp to 270 GeV to see the beam behaviour and prepare for the following MDs.

MD 3 & 4: Crab Cavity Transparency & Performance

- **Aims**
  - To determine to what level the cavities can be made transparent.
  - To show that the cavities can be manipulated and controlled accurately.
  - To understand the beam behaviour in the presence of CCs.
- **Steps:**
  - Inject and ramp single/multiple bunches with low intensity.
  - Operate the cavities in transparent mode
    - Move between transparent and phased mode smoothly.
  - Increase beam current from 2×10^{10} to 1×10^{11}.
  - Check transparency for several low intensity bunches.
  - Cavity and cryo performance vs total beam intensity.

MD 3 & 4: Crab Cavity Transparency & Performance

- **Steps (cont):**
  - CC RF manipulations
    - Voltage ramping, phase manipulation, long term stability
  - Measurement of rf multipoles (a3)
  - Tune shift with intensity (to be compared with results from a parallel MD)

Parallel: Failure Tests

- **Aims**
  - Observe beam behaviour for different cavity failure scenarios
- **Steps**
  - Failure scenarios can be driven (voltage drop, change of phase or detuning) and BPMs, BLMs and cavity signals can be recorded.
  - The table below shows a checklist that can be filled (priority in superscript). This will provide important information on criticality of the tested failure cases for SPS and HL-LHC. See talk by D. Wollmann.

Failure (right) Mode (below)	Voltage Drop with LLRF[1]	Phase Jump with LLRF[1]	Phase Jump[2]	Voltage Drop[2]	Detuning with high voltage[2]	Detuning on Resonance[3]
Phased						
Counter-phased						

[1] With the LLRF trying to compensate for the failure by matching the voltage/phase to the other cavity.

MD 5: Emittance Growth in Coast

- **Aims**
  - To measure the emittance growth in coast in the presence of the crab cavities.

- **Steps:**
  - Set up crab cavity in coast at $270\ \mathrm{GeV}$ with a single bunch (2×10^{10})
  - Operate cavity in phased mode and transparent mode and measure the emittance growth with the available diagnostics.

MPP between MD5 and MD6

- **Aims**
  - Review the experience gained with crab cavities before moving to high intensities.

- **Things to review:**
  - Measurements from cavities used to update the failure models

  - Failure experiments compared with simulations

  - Operational experience: failure rates, severity, time scales of failures etc

  - Available mitigations and necessity of interlocking RF signals

MD 6 & 7: High Intensity

- **Aims**
  - To better understand the performance of the cavities when operating with high intensity beams.

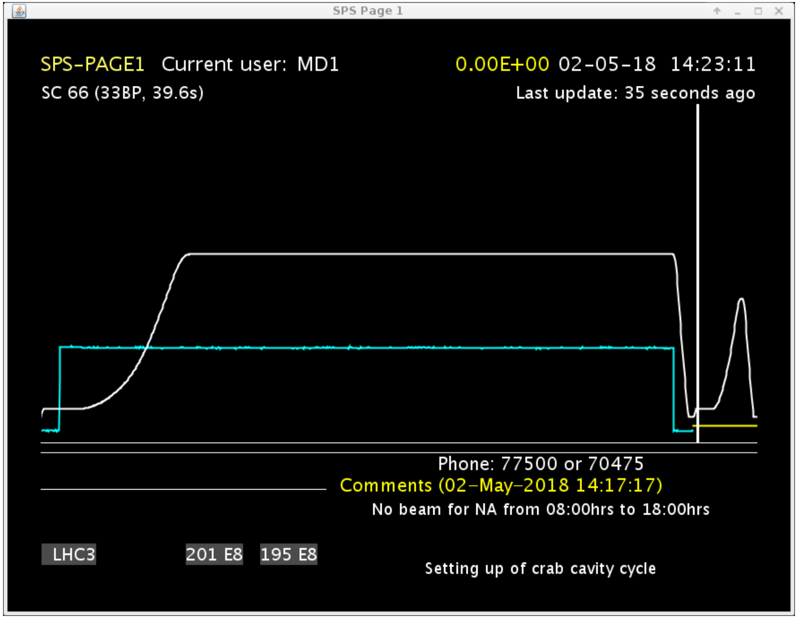
- **Steps:**
  - Cavity stability with trains
    - Trip rate, quench field vs beam current, fast transients
  - Beam loading with growing 4 corrector bumps and effect of bunch non-linearity (1ns bunch length vs 2ns bunch length).
  - Excitation of different HOMs with different filling schemes
  - Cryogenic load & stability
  - Fast phase shift (by operator request) or close to a known multipacting band (~0.2-0.5 MV)

MD Preparation: SPS Cycles

- **Two new cycles have been setup in the SPS specifically for the crab cavity MDs.**

- MD_CRAB_26_L26400_Q26_2018_V1 - 26 GeV with **19.12s FB**.
- MD_CRAB_26_270_L30000_Q26_2018_V1 - 270 GeV with **26.6s FT**

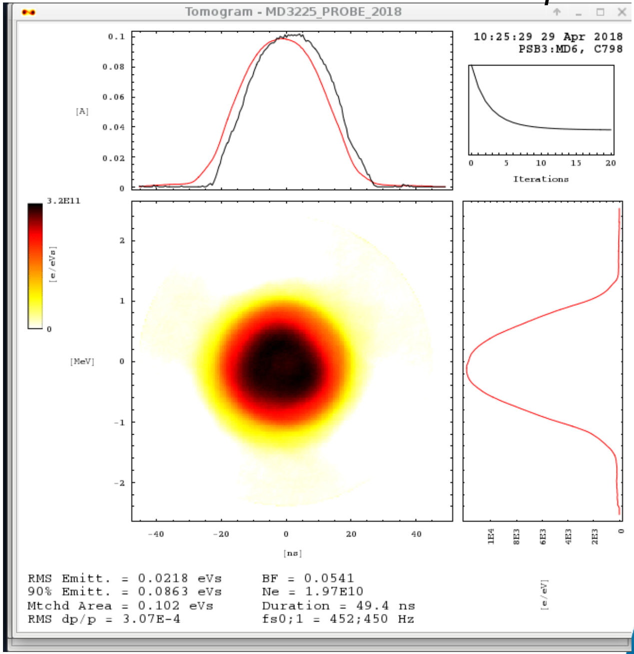
Both cycles still need some fine tuning but are mostly ready to go



MD Preparation: PS Booster

- **In case of lifetime issues at 26 GeV (see presentation by A. Alekou), a beam has been developed in the PSB with low longitudinal emittance and bunch intensities of 2×10^{10}.**
- MD_3225_PROBE_EvNorm_2018 (0.2eVs = ~2.2ns)
- MD_3225_PROBE_EvLow_2018 (0.1eVs = ~1.4ns)

Many thanks to F. Chapuis

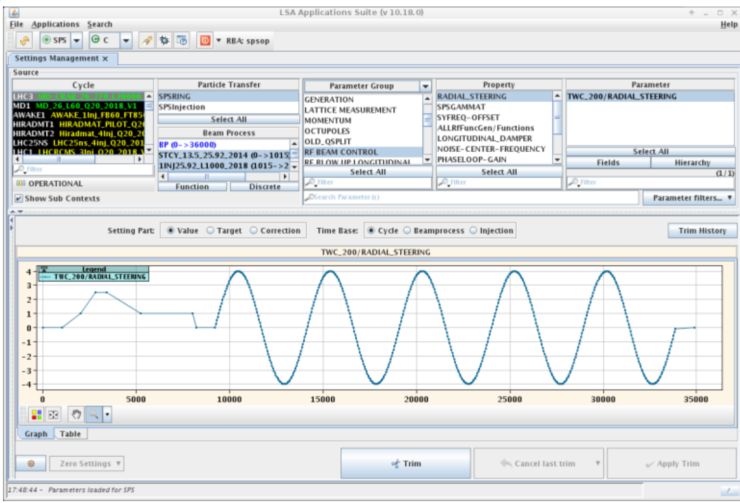


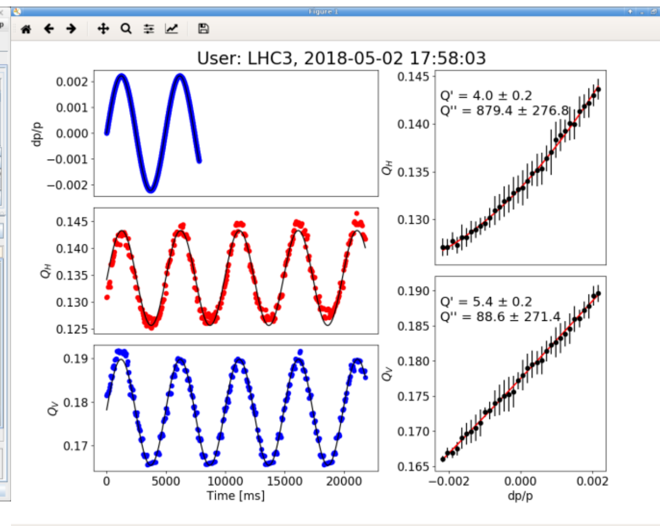
- Both bunches were able to be stabilized at 26 GeV.

MD Preparation: Chromaticity

- **To speed up chromaticity measurements, an LHC-like RF modulation has been tested and verified.**

- Now it should only require 1-2 cycles to get a chromaticity measurement.
- No need for Auto Q which could take a lot of time using the long cycles.



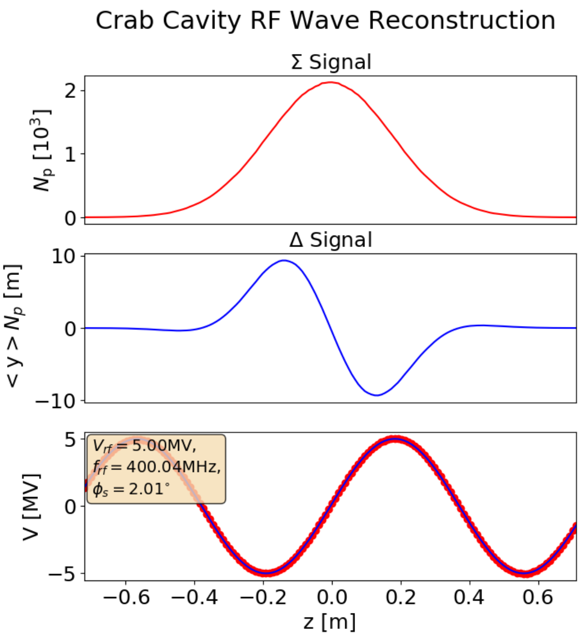


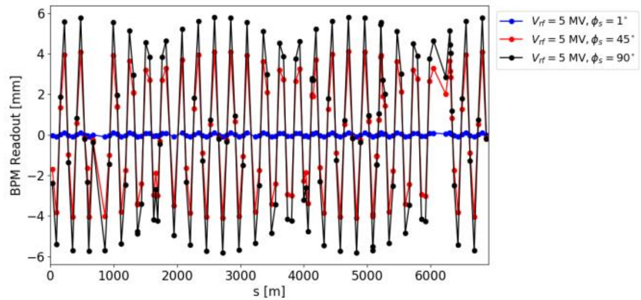
MD Preparation: Re-phasing

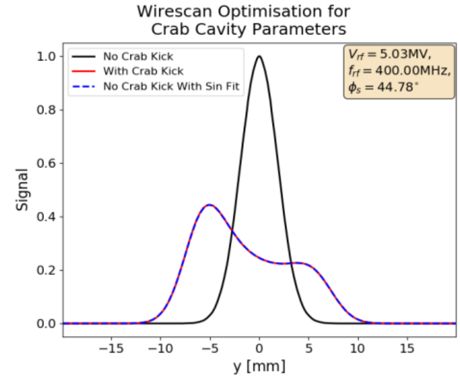
- Until 2017, re-phasing used only at 450/400 GeV for LHC/AWAKE beams
- Crab cavities impose new requirements
- Tested at 270 GeV and now operational. Display of phase error is not currently available.
- For 26 GeV, the FESA class needs some modification.
- New timing functionality needs to be added to start the re-phasing from flat bottom.
- FESA class has been prepared and will be tested on 08/05/18.
- *Many thanks to G. Papotti and T. Bohl.*
- See talk by P. Baudrenghein for more details.

MD Preparation

- **Scripts developed to calculate crab cavity parameters from beam diagnostics. See talk by T. Levens for more information on BI hardware upgrades.**
- Works for simulation, setup for measurement but no data to test.







Summary

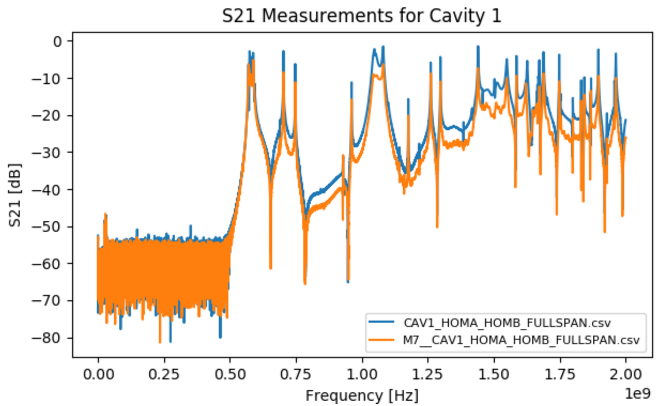
- **The defined test program is ambitious but achievable.**
- First MD test is tentatively planned for 23rd May 2018, taking into account the present status & MD planning
- A lot of preparation has already occurred with lots of input from a wide circle of people.
- **Please do not hesitate** to give your opinion about the MD program that is being presented.

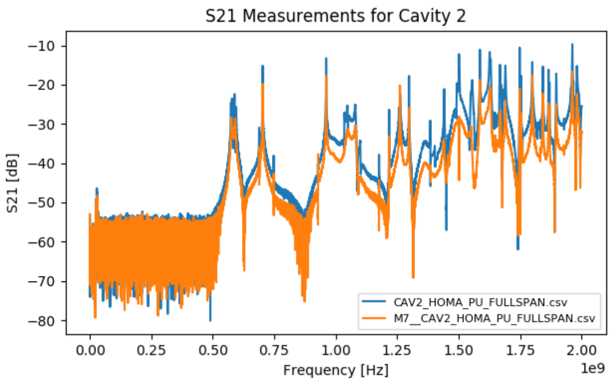
Thank you

Backup

Current Status

- Frequency measurements
  - HOM spectrum for cavity 1 & 2, comparison between SM18 and SPS (J. Mitchell)





Current Status - Equipment Check

- First "MD" in the SPS on 2nd May, testing the movement of the table
- General Sequence
  - No access, liquid level at ~60%
  - Close SPS sector valves
  - Table movement (~ 10 min)
  - Open CM valves (checked vacuum profile, ok) and then open SPS sectors valves
  - Safety checks (interlock and access)
- Still need to pass to remote movement of the table from CCC instead of BA6

Optics Parameters at Key Elements

Device	Pickup Name	s [m]	β_x [m]	β_y [m]	μ_x	μ_y
Crab Cavity 1	ACFCA.A1.LSS6	6312.7213	29.94	78.17	23.8766	23.9030
Crab Cavity 2	ACFCA.B1.LSS6	6313.3213	31.07	75.85	23.8797	23.9043
HeadTail-PU	BPCL.42171	4145.0317	48.78	49.43	15.6863	15.6803
Wideband PU	BPWB.32101	2974.0697	23.01	95.61	11.2235	11.2775
LHC BPM 1	BPMCA.61736	6311.6590	28.05	82.40	23.8708	23.9009
LHC BPM 2	BPMCA.61751	6314.5190	33.45	71.33	23.8857	23.9069
Wirescan 416	BWSB.41677	3989.6339	38.04	62.95	15.0486	15.14021
Wirescan 517	BWSD.51731	5155.1062	21.38	101.57	19.4863	19.5280
Wirescan 519	BWSA.51995	5242.5423	81.50	28.15	19.8230	19.8436
Electro-Opt PU	BPMEA.42172	4145.747	50.83	47.43	15.6886	15.6827

Taken from MAD-X for Qx=26.13, Qy=26.18, Q'x=1, Q'y=1
Origin of this table can be found here.